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Naturalization and potential impact of the exotic tree *Azadirachta indica* A.Juss. in Northeastern Brazil

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ABSTRACT: Invasive species are among the leading causes of biodiversity loss on the planet, and some species that have become invasive were intentionally introduced for ornamental or commercial purposes. *Azadirachta indica* A.Juss. (Indian neem) is an exotic species that is widely cultivated in the northeastern region of Brazil, both in plantations and as an ornamental or shade tree, where it has reached reproductive phase in recent years. In order to assess its level of naturalization and the geographic range where this species has reproductive capacity, we observed *A. indica* specimens cultivated in Fortaleza (Ceará) since 2006 and performed field observations in several other localities in Ceará, Rio Grande do Norte, Paraíba and Piauí states. Currently, the species reproduces near the coast as well as in the semiarid interior of the Northeast, and is able to establish regenerating populations. Thus, the species is naturalized in Brazil with the potential to become invasive in the near future.

Invasion by exotic species is one the major causes for the loss of biodiversity (Vitousek *et al.* 1997; Richardson *et al*. 2000). Most of the intentionally or accidentally introduced species by humans do not cause any damage to the native species or ecosystems. However, some of the exotics can reproduce in the new regions after being introduced and may turn into a problem, competing with the native species and changing the structure and composition of local ecosystems (Richardson 1998; Richardson *et al*. 2000).

Plants used for economic (timber, forage, pulp production, etc.) or ornamental purposes, can spread as invasive plants beyond their cultivation area and become environmental pests (Richardson 1998; Reichard and White 2001; Zipperer 2002; Harrington *et al*. 2003; Andrade *et al*. 2009). *Azadirachta indica* A. Juss. (Meliaceae), the Indian neem, is a tree native to Asia which was officially introduced to Brazil in 1986 (Neves and Carpanezzi 2008; 2009). Since the 1990's the species has been cultivated commercially in the Southeast, Midwest, North and Northeast of Brazil. In the latter region, it has been grown in urban and rural areas as an ornamental or shade tree, as a windbreak, in hedges, or for commercial biopesticide production (personal observations; Moro and Westerkamp 2011). Due to its insecticidal properties and commercial value (*e.g.* Schmutterer 1990; Ascher 1993; Neves and Carpanezzi 2008; 2009), this species has received much support and advertising by the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA) and by non-governmental organization (NGOs) in Brazil. They consider that its use in organic agriculture and forestry would be beneficial for the production of both timber and bio-insecticides (making the use of synthetic pesticides unnecessary).

Rapid plant growth, abundant seed production and easy seedlings establishment have also stimulated commercial gardeners, EMBRAPA, NGOs and citizens of Northeastern Brazil to propagate *A. indica* for commercial plantations and for ornamental purposes. This makes Indian neem currently one of the most common species cultivated for urban and rural afforestation in many towns of the Brazilian Northeast (e.g. Moro and Westerkamp 2011).

The capacity of rapid growth and production of many seeds, however, are indicative of invasiveness and possible environmental problems. In a growth experiment performed in field conditions in Rio Grande do Norte state, *A. indica* reached 2.4 m in height only one year after being sown, and 3.7 m in the second year (Silva *et al*. 2007). Nevertheless, the potential invasiveness of *A. indica* has been ignored by those advocating its cultivation, similar to the case of mesquite (*Prosopis juliflora* (Sw.) DC. - Fabaceae), which, despite its many uses, has become a serious environmental problem in Northeastern Brazil (Pegado *et al*. 2006; Andrade *et al*. 2009). *A. indica* was introduced to Brazil without enough risk-assessments about the potential environmental problems it could generate. We have here investigated the current level of naturalization of *A. indica* in Northeastern Brazil and wish to draw attention to its bioinvasive potential and potential harm to natural ecosystems, if this species reach invasive status.

The process of dissemination and cultivation of *A. indica* trees in both urban and rural zones of many towns in Northeastern Brazil has been monitored by the authors since 2006. Additionally, some specimens used as ornamental trees have been observed since 2006 in two locations in the city of Fortaleza, state of Ceará. One of them was the Cocó Ecological Park (Parque Ecológico de Cocó, 3°44'44.94" S 38°29'01.48" W), the other was the Pici *Campus* (*Campus* do Pici: Biology Department, 3°44'43.57" S 38°34'28.45" W; and University's Plant

Nursery, 3°44'22.64" S 38°34'35.10" W) of the Federal University of Ceará (Universidade Federal do Ceará, UFC). The Cocó Ecological Park was selected because of its environmental importance as a biodiversity conservation area, and the Pici *Campus* for accessibility, a precondition for long term observations.

The Cocó Ecological Park in Fortaleza is a protected area completely surrounded by heavily urbanized areas. The Pici *Campus* is an urbanized area, but contains a small fragment of native semi-deciduous forest ("mata de tabuleiro" forest), experimental agricultural areas and a large proportion of unpaved open areas, all of which are potential sites for *A. indica* invasion. In 2005, the first specimens of *Azadirachta indica* were seen growing on the Pici *Campus* (Marques, 2005); since then, this species was planted here as an ornamental and shade tree with increasing intensity.

We began our monitoring at Pici *campus* in 2006, when four saplings (less than 2 m high) of *A. indica* were planted by the university in the Biology Department. We also located in the same year two adult individuals planted as shade trees and seed source for seedling production in the plant nursery. From 2006 to 2011 we made observations whether these cultivated trees had reached reproductive maturity and whether spontaneous seedlings could be found around them. In 2007 we begin our observations at Cocó Park. There we observed many cultivated trees bearing fruits and also spontaneous seedlings at the edge at the park.

Fortaleza is a coastal city, where the climate is milder and more humid than in the interior. To investigate whether *A. indica* could reproduce both in coastal areas and in the drier interior of Northeastern Brazil, we made excursions to municipalities in the interior and coast of Ceará, Rio Grande do Norte, Paraíba and Piauí states between 2009 and 2011, where we observed whether cultivated plants were reproducing.

To define the degree of naturalization of *A. indica* we followed the terminology proposed by Richardson *et al*. (2000) and Pyšek *et al*. (2004). In which 1) an exotic species is a species brought by human action to an area beyond the natural distribution of the species; 2) a naturalized species is an exotic species that reproduces in the area to which it was introduced and is able to establish and sustain a population in the new range without human aid; and 3) an invasive plant is a species that is able not only to maintain a viable population, but also to spread from the site of introduction to new sites, establishing further populations.

Since 2006, the cultivation of *Azadirachta indica* has strongly increased in Northeastern Brazil, in both commercial plantations and as ornamental or shade trees. Currently, it is one of the most-planted ornamental trees in several Northeastern towns (e.g. Moro and Westerkamp 2011). In March 2007, the specimens cultivated in the surroundings of the Cocó Park had reached the reproductive stage. Below the canopy of mature trees of Cocó Park we recorded hundreds of seedlings of this species (Figure 1). Although density of seedlings was highest directly below the parental trees, seedlings were also found at distances of up to 20 m from the parents. Since that first observation in 2007, several additional specimens of *A. indica* have been planted as ornamental trees in the surroundings of the park. In 2009, we recorded that seedlings began to grow inside the park, although these were confined to the edges.

On the Pici *Campus*, the adult *A. indica* trees monitored produced fruits and seedlings in a similar manner to that observed at Cocó Park. The specimens cultivated near the Biology Department, which were juveniles in 2006, grew into reproductive adults in 2009 (founders - 1st generation) and produced spontaneous seedlings (2nd generation) from 2009 onward. These seedlings were observed both under the canopy of parental trees and up to 47 m away from them. Spontaneous seedlings that germinated in 2009 (second generation) reached reproductive maturity in January 2011, setting their own fruits, which in turn gave rise to seedlings (3rd generation). It took only five years to this species to produce three generations: beginning with cultivated saplings in an ornamental garden resulted in an area with 47 m of radius where we find 2nd generation reproductive adults, 3rd generation seedlings and hundreds of seeds from both 1st and 2nd generations. This suggests that in the long term *A. indica* may have the capacity to become a widespread invasive species that is difficult to control.

In the University's Plant Nursery, the cultivated trees (founders - 1st generation) had also spontaneously produced a large number of seedlings (2nd generation) in February 2007, some of which were growing at a distance

Figure 1. Spontaneous seedlings of *Azadirachta indica* growing under parental trees in 2007, in the surroundings of Cocó Ecological Park, Fortaleza, Ceará, NE Brazil. The large leaved seedling in B is a native species, which has now to compete with hundreds of *A. indica* seedlings when trying to grow.

of over 30 m from the parent trees. In December 2009 (34 months later), three individuals of the 2nd generation, which were juveniles in 2007, had already become reproductive adults more than 4 m high and produced their own seeds and seedlings (3rd generation).

The first neem trees planted in the Pici *Campus* (founders) were probably introduced shortly before 2005, since their presence as cultivated trees in the *campus* was first reported by Marques' undergraduate thesis (Marques, 2005; Voucher in the EAC herbarium: number 34.913; V.B. Marques s/n, 08.04.2005). These cultivated individuals generated spontaneous seedlings that reached maturity and produced their own offspring. If we assume that the specimens we have been monitoring in the UFC plant nursery had been planted at the most 5 years prior to 2005 (Marques 2005), 5 to 10 years had passed until the species completed its naturalization process, having produced three generations. The same occurred with the neem trees observed in the Biology Department: The first individuals (1st generation) where planted in 2006 and their 2nd generation produced fruits (3rd generation) in January 2011, five years after the initial plants were first cultivated.

These two sets of observations indicate that naturalization occurred in the span of 5 to 10 years. These data are consistent with Neves and Carpanezzi (2008; 2009), who reported the species first flowering in just 18 months after planting, and Silva *et al*. (2007), who observed the capacity of this species to grow very fast in NE Brazil.

During excursions to the interior of Brazil's Northeastern region (in December 2009, January 2010, January 2011 and December 2011), we found that *Azadirachta indica* was capable of producing fruit and seedlings in both more humid coastal areas and also in semiarid inland areas where *Caatinga* vegetation occurs. We observed flowering individuals in Alto do Rodrigues, Areia Branca, Baraúna, Caicó, Caraúbas, Governador Dix-Sept Rosado, Ipanguaçu, Macau (inside the Ponta do Tubarão Reserve for Sustainable Development), Mossoró, Natal and São Rafael municipalities in Rio Grande do Norte state; Campina Grande, João Pessoa, Junco do Seridó and Várzea in Paraíba state; Amontada, Aquiraz, Aracati, Aurora, Caucaia, Chorozinho, Eusébio, Forquilha, Fortaleza, Horizonte, Icó, Irauçuba, Itaitinga, Itapajé, Itapipoca, Itarema, Jaguaribe, Jaguaribara, Jijoca de Jericoacoara (inside the Jericoacoara National Park), Limoeiro do Norte, Martinópole, Massapê, Miraíma, Morada Nova, Morrinhos, Pacajus, Russas, Santana do Acaraú, São Gonçalo do Amarante, São Luiz do Curu, Senador Sá, Sobral, Tururu, Umirim and Uruoca in Ceará state; and Altos, Campo Maior, Ilha Grande, Parnaíba and Teresina in Piauí state (Figure 2).

We also observed spontaneous seedlings near parent trees in Baraúna, Caicó, Ipanguaçu, Mossoró, Campina Grande, Aurora, Russas, Morada Nova, Jaguaribara, Aquiraz, Caucaia, Fortaleza, Sobral, Forquilha, Massapê, Senador Sá, Uruoca, Itapajé and Jijoca de Jericoacoara (including the coastal Jericoacoara Village, inside the Jericoacoara National Park) (Figure 2). This indicates that the species might spread over a wide area in both the semiarid interior and coastal zones of Northeastern Brazil.

Azadirachta indica shows precocious reproduction and fast growth in a variety of conditions of Brazil. It produces a large number of seeds per tree that can be dispersed to large distances from the parental plants, generating a great number of seedlings. These features suggest that this species has potential to become invasive within a few years.

Figure 2. Municipalities in NE Brazil where we observed reproductive specimens of *Azadirachta indica*. Circles: trees observed bearing flowers or fruits. Triangles: spontaneous seedlings also observed close to cultivated trees (see text for a complete list of place names).

According to Neves and Carpanezzi (2008; 2009), commercial plantations of neem can produce up to 6 kg of seeds per tree per year, each kilogram containing approximately 3,000 seeds. If these data are correct, one tree growing under ideal conditions could produce annually thousands of seeds. Considering that seeds are produced and dispersed abundantly and that a sapling of this species may grow up to 3.7 m in height in two years (Silva *et al*. 2007), we should be extremely concerned about the potential environmental impact and the difficulties to control this species once it became invasive.

Commercial plantations of neem are economically productive in various climatic and edaphic conditions all over Brazil (Neves and Carpanezzi 2009), demonstrating that the species is widely adapted to different environmental conditions in the American continent and that the potential area for invasion extends far beyond Northeastern of Brazil. Considering that *Azadirachta indica* has established spontaneous seedlings here, which in turn are spontaneously producing their own offspring without human aid, we conclude that the species is already naturalized (*sensu* Richardson *et al*. 2000).

Moreover, seedlings were recorded at increasing distances from the parent trees in each sequential observation we made over 5 years. This suggests that within a few years the species will be able to disperse over distances compatible with the "invasive species" category of Richardson *et al*. (2000). Hence, monitoring and control programs are urgently necessary in this initial stage to prevent *A. indica* from becoming invasive. When an invasive plant becomes very established and widespread in a new region, eradication is often impracticable and control programs are very costly, which frequently leads control programs to fail (Gardener et al. 2012). Proper quarantine and Weed Risk Assessments offer a more efficient and secure method to prevent plants of becoming invasive in new regions (Gardener et al. 2012). The introduction of *A. indica* in Brazil was aimed at economic gains, but didn't consider the economic and environmental risks related to biological invasion.

As signatory of the Convention on Biological Diversity, Brazil has a duty to "Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (Convention on Biological Diversity, Article 8-h). As the species is now naturalized and evidence suggests that it will become invasive, action should be taken to reduce the impact of this species. Although *A. indica* has become a common tree in urban forestry of Northeastern Brazil (Moro and Westerkamp 2011), wherever possible, this species should be removed in order to prevent it becoming more widespread.

Based on the evidence we have gathered, we make a number of recommendations to reduce the impacts of this species on native biodiversity:

1. The removal of *A. indica* trees grown in the vicinity of natural protected areas.
2. The Government should not grant permission for any new commercial plantations until the bioinvasive risks of the species is better assessed and control protocols are developed.
3. Where there is a need for ornamental or shade trees, we strongly recommend the replacement of this exotic species with natives.
4. Monitoring and control programs should be established in areas of commercial cultivation, to avoid or at least minimize the escape of this species from the planted area to the surroundings.

These precautions are the best way to prevent this naturalized species becoming so well established that control is impossible or far too costly.

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